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16. Abstract The induced trench method of culvert construction is used to reduce the loads on a culvert under a high fill. Although the method has been used successfully with culverts under some unusually high fills, the magnitude of the reduction in load is not clearly defined. This research project was undertaken to provide a better understanding of the loads imposed by the overburden soil when utilizing the induced trench method of culvert construction. This report describes the construction and instrumentation of a 7- by 7-foot reinforced concrete box culvert installed under a high fill by the induced trench method. Problems encountered with the instrumentation are described and recommendations for instrumenting future installations are presented. An electro-magnetic differential transformer (EMDT) was used on the project for measuring embankment settlements. This device appears to have great potential for accurately measuring the settlements within embankments during and after construction.			
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CONSTRUCTION AND INSTRUMENTATION OF INDUCED
TRENCH EXPERIMENT UNDER HIGH FILL

By

Floyd K. Jacobsen and Robert E. Clark

Interim Report IHD-19

Induced Trench Experiment Under High Fill

A Research Project Conducted by
Illinois Department of Transportation
in cooperation with
U. S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

April 1979

SUMMARY

The construction of underground drainage structures in accordance with the high safety standards developed for the Interstate Highway System has led to increased costs for culvert installations. One proposed method of reducing culvert costs is the induced trench procedure developed by the late Dean Marston of Iowa State College. Although the method is known to result in a substantial reduction in loads on a culvert, the magnitude of the load reduction has not been clearly defined.

An important parameter used in the analysis of the induced trench is the settlement ratio. This ratio indicates the amount of differential settlement occurring between the column of soil directly above the culvert and the adjacent soil and is used to determine the magnitude of the loads acting on the culvert. If the settlement ratio for an induced trench installation can be established, the working loads acting on the culvert can be estimated with reasonable accuracy. Because current knowledge of the settlement ratio is based on limited experimental data, an evaluation of the settlement ratio is needed from a number of field installations to establish criteria for designing culverts constructed by the induced trench method.

This research project was undertaken in 1973 with the construction and instrumentation of a 7- x 7-ft (2.13- x 2.13-m) reinforced concrete box culvert bedded on rock and installed, by the induced trench method, under varying fill heights up to 100 ft (30.48 m). The instrumentation consists of settlement measuring devices for determining the settlement ratio and the location of the plane of equal settlement. The culvert barrel is instrumented with strain gauges to indicate the load behavior for analysis of the soil-structure system.

An electro-magnetic differential transformer (EMDT) was designed and fabricated for use on the project. This device appears to have great potential as a means of measuring embankment settlements.

This report describes the construction and instrumentation of the induced trench installation under a high fill. Also included are problems encountered during instrumentation and recommendations for future instrumentation of similar projects. A final report will cover the data analysis.

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CONSTRUCTION AND INSTRUMENTATION OF INDUCED TRENCH EXPERIMENT UNDER HIGH FILL

INTRODUCTION

The low profiles and flat grades of the Interstate highway system have required the construction of relatively long culverts under high earth fills. Accordingly, the cost of constructing the culverts with sufficient strength to withstand the heavy overburden loads has greatly increased. A means of reducing the load on such culverts could provide considerable savings.

The induced trench method of culvert construction has been used successfully to reduce the earth loads on culverts under normal fill heights. Although a reduction in loads is known to be substantial, the magnitude of the load reduction has not been clearly established. A designer attempting to analyze a culvert to be installed by the induced trench method is handicapped by the lack of supporting data, and must make certain design assumptions which are thought to be conservative.

The concept of installing underground conduits by the induced trench method was first introduced in the early 1920's by Dean Anson Marston^{1/}, and analyzed mathematically in 1950 by M. G. Spangler^{2/}, both of Iowa State University. The purpose of the induced trench, which is constructed by removing a prism of material directly above the culvert and refilling the trench with a loose compressible material, is to insure that the column of soil directly above the culvert will settle downward relative to the adjacent soil within the embankment. The differential settlement produces shearing forces which act upward on the column of soil above the culvert and which reduce the load acting on the culvert. Theoretically, the magnitude of the differential movement will diminish to zero at some distance above the top of

the culvert and below the top of the embankment. The plane at which the relative movements cease and above which no shearing forces act is termed the plane of equal settlement. The concept of a plane of equal settlement beneath the top of the embankment is an important factor when considering the use of the induced trench, because the formation of such a plane means that differential settlement will not occur throughout the height of the embankment and a localized sag will not occur in the roadway.

Several states have reported favorable results from the use of the induced trench. Montana^{3/} used the induced trench to reconstruct an 18.5-foot (5.64-m) diameter structural plate pipe with up to 83 feet (25.30 m) of rock fill after failure of the original structure. The induced trench was constructed using a 3-foot (0.91-m) layer of baled straw above the culvert to reduce the vertical load on the structure. The instrumentation consisted of strain, pressure, and settlement-measuring devices. The investigation showed that the imperfect trench functioned in essentially the anticipated manner and limited the vertical load to approximately half the weight of the overburden.

The Kentucky Department of Highways^{4/} installed a 48-inch (1.22-m) Class III reinforced concrete pipe partially by standard bedding methods and partially by using the induced trench method. A total of 102 4-foot (1.22-m) pipe sections from a design length of 140 sections were placed by standard bedding methods. The remaining 37 sections actually placed were installed by the induced trench procedure. Distress in the form of cracks as wide as 1/4 inch (6.4 mm) was observed in the pipe laid by conventional methods; however, no distress was observed in that portion of the pipe installed by the induced trench method.

In 1960, the Illinois Department of Transportation and the American Concrete Pipe Association conducted a research study^{5/} to determine values of the

settlement ratio and the loads acting on a 48-inch (1.22-m) RC pipe culvert under 30 feet (9.14 m) of fill installed by the induced trench method of construction. The results of the study indicated that the settlement ratio was within the range of -0.3 to -0.5, which agrees with theoretical values recommended for the induced trench method of construction. A comparison of the theoretical and measured loads acting on the culvert indicated that the measured loads were about 50 percent of the theoretical loads. The results of the study indicated that the theory was rational and it was recommended that the theory, which appears to be conservative, is acceptable and should be used. The study also suggested that further studies be made, especially under higher fills.

A second study was undertaken in 1973, with the construction of the project completed in the latter part of 1977. The project included instrumentation of a 7- x 7-foot (2.13-x2.13-m) concrete box culvert bedded on rock and installed under varying fill heights up to 100 feet (30.48 m). The instrumentation consists of settlement-measuring devices for determining the settlement ratio and the location of the plane of equal settlement. The culvert barrel is instrumented with strain gauges to indicate the load behavior for analysis of the soil-structure system.

This report describes the construction and instrumentation of the induced trench installation under a high fill. The experimental culvert is incorporated in the construction project identified as FAI 474, Section 72-3, Project (I-474-7()). The site is located in Peoria County near Peoria, Illinois (Figure 1).

THEORETICAL CONCEPTS

The purpose of the induced trench is achieved as the column of soil above the culvert settles downward relative to the adjacent compacted soil. The



Figure 1. General terrain profile at culvert location in Peoria County.

relative movement generates shearing forces which act upward on the interior prism of soil as illustrated in Figure 2. The shearing forces support part of the weight of the column of soil above the conduit, thereby reducing the load on the culvert.

If the embankment is sufficiently high, the shearing forces may terminate at a horizontal plane within the embankment which is termed the plane of equal settlement. Above this plane no relative settlements occur and no transfer of load takes place. If the embankment is not sufficiently high, no plane of equal settlement will develop beneath the top of the embankment. In that case, differential settlement will occur throughout the height of fill above the culvert. This situation, which is termed the complete ditch condition, possibly could result in a localized sag in the roadway. One of the engineer's primary concerns when considering the use of the induced trench is the possibility of an eventual settlement of the roadway above the culvert.

When measuring the settlement at a conduit, it is convenient to establish a horizontal reference plane, which is usually referred to as the critical plane. In the case of the induced trench, the critical plane is the horizontal plane which passes through the top of the trench (Figure 2). The top of the trench is located at a distance $p' B_d$ above the top of the culvert where the projection ratio (p') is the ratio of the distance between the top of the trench and the top of the conduit to the width of the induced trench (B_d).

An important parameter to be considered when analyzing the induced trench is the settlement ratio. This ratio is an indication of the magnitude of the relative movements of the prism of soil directly above the conduit and the adjacent soil and is used in computing the design loads on the culvert. The settlement ratio for the induced trench is calculated by the following formula:

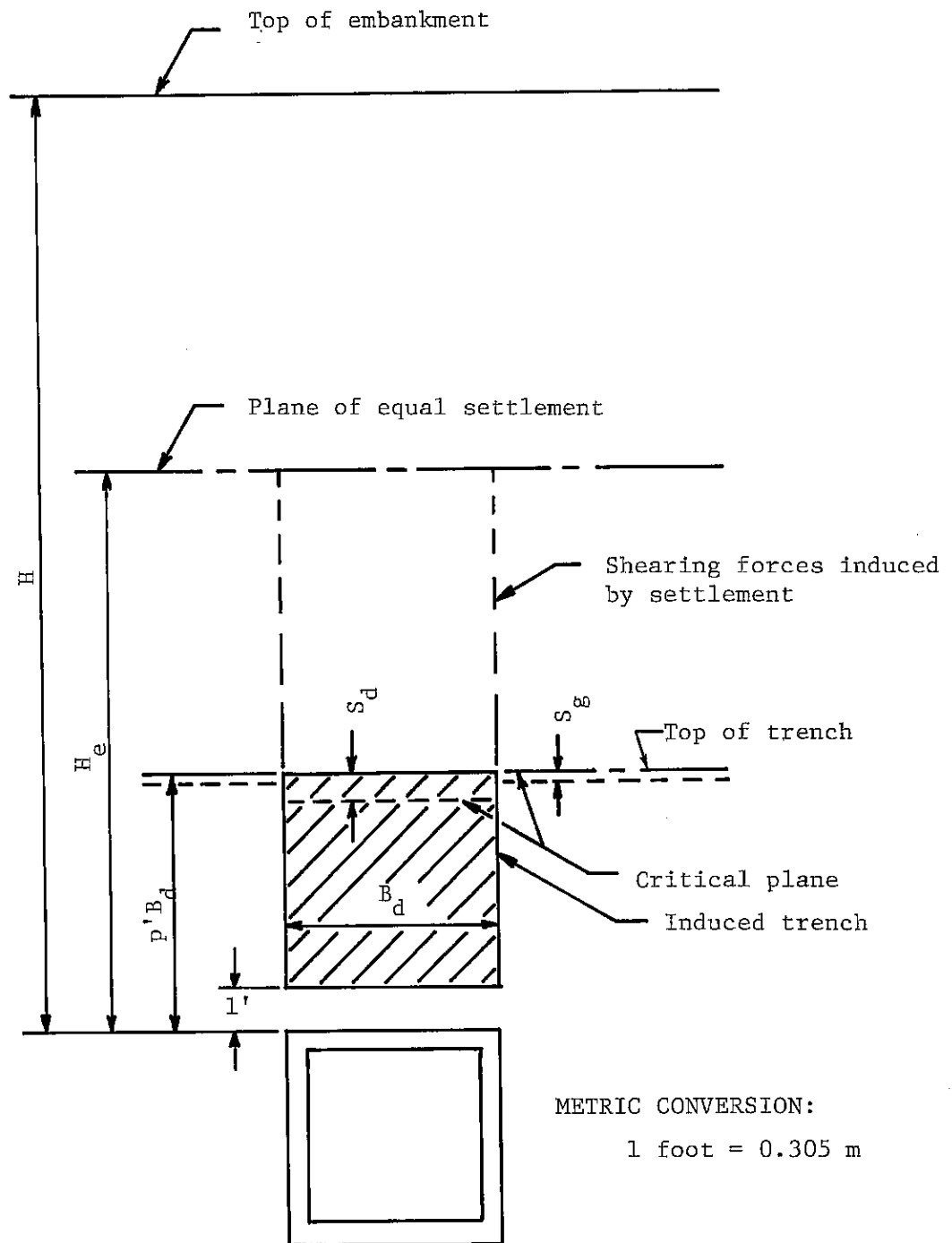


Figure 2. Settlements which influence loads on induced trench culverts.

$$(1) \quad r_{sd} = \frac{S_g - (S_d + S_f + d_c)}{S_d}$$

Where r_{sd} = settlement ratio

S_g = settlement of the compacted embankment at the level of the top of the trench and adjacent to the sides of the trench

S_d = deformation of fill from the top of the culvert to the top of the trench

S_f = settlement of flow line of conduit

d_c = shortening of the vertical dimension of the culvert

On the basis of the computed settlement ratio, charts have been developed by Spangler^{2/} whereby the theoretical loads on the conduit can be determined from the following formula:

$$(2) \quad W_c = C_n w B_d^2$$

Where W_c = load per linear foot of conduit

C_n = a load coefficient which is a function of the ratio of the height of fill to the width of ditch H/B_d ; of the projection ratio p' ; of the settlement ratio r_{sd} ; and of the coefficient of internal friction u

w = unit weight of backfill

B_d = width of trench = width of culvert

In the derivation of the load theory for underground conduits, Marston pointed out that the influence of the coefficient of internal friction (u) of the fill material is relatively minor and, therefore, the product of Rankine's lateral pressure ratio (K) and the coefficient of internal friction may be safely assumed equal to 0.13 for the induced trench.

Since the culvert under investigation in this study is bedded upon rock, no settlement of the flow line should occur. Therefore, the term S_f in the equation for the settlement ratio can be assumed to be negligible. The equation originally was derived for a pipe culvert installed by the induced trench method. The term d_c for a pipe would represent a shortening of the vertical pipe diameter. Because the corners of the rigid frame box culvert to be studied should have a very small vertical deflection, the effect of d_c on the settlement of the column of soil above the culvert should be slight and for all practical purposes can be considered negligible. The equation for the settlement ratio of the culvert under study then reduces to the following:

$$(3) \quad r_{sd} = \frac{S_g - S_d}{S_d}$$

CONSTRUCTION

The culvert construction site was located in a natural ravine which had a depth of approximately 100 feet (30.78 m) and a calculated drainage area of 374 acres (151.35 hectares). As the I-474 highway would cross this ravine transversely, a high fill would be necessary to attain pavement grade level. The fill area would vary up to 110 feet (33.53 m) in depth and have a width, parallel to the culvert, of 726 feet (221.28 m).

Construction of the project began in June 1976 with the excavation of a 735-foot (224.03-m) long trench to a depth of approximately 12 feet (3.66 m). The base width of the excavation remained more or less constant at 12 feet, while the top width varied depending on composition of material in that section. The sidewall slope varied from near vertical to approximately 1:1. (Figure 3).

A lean-mix concrete pad of varying thickness was used to seal the exposed surface of the bedrock from seepage of underground water and to level the surface

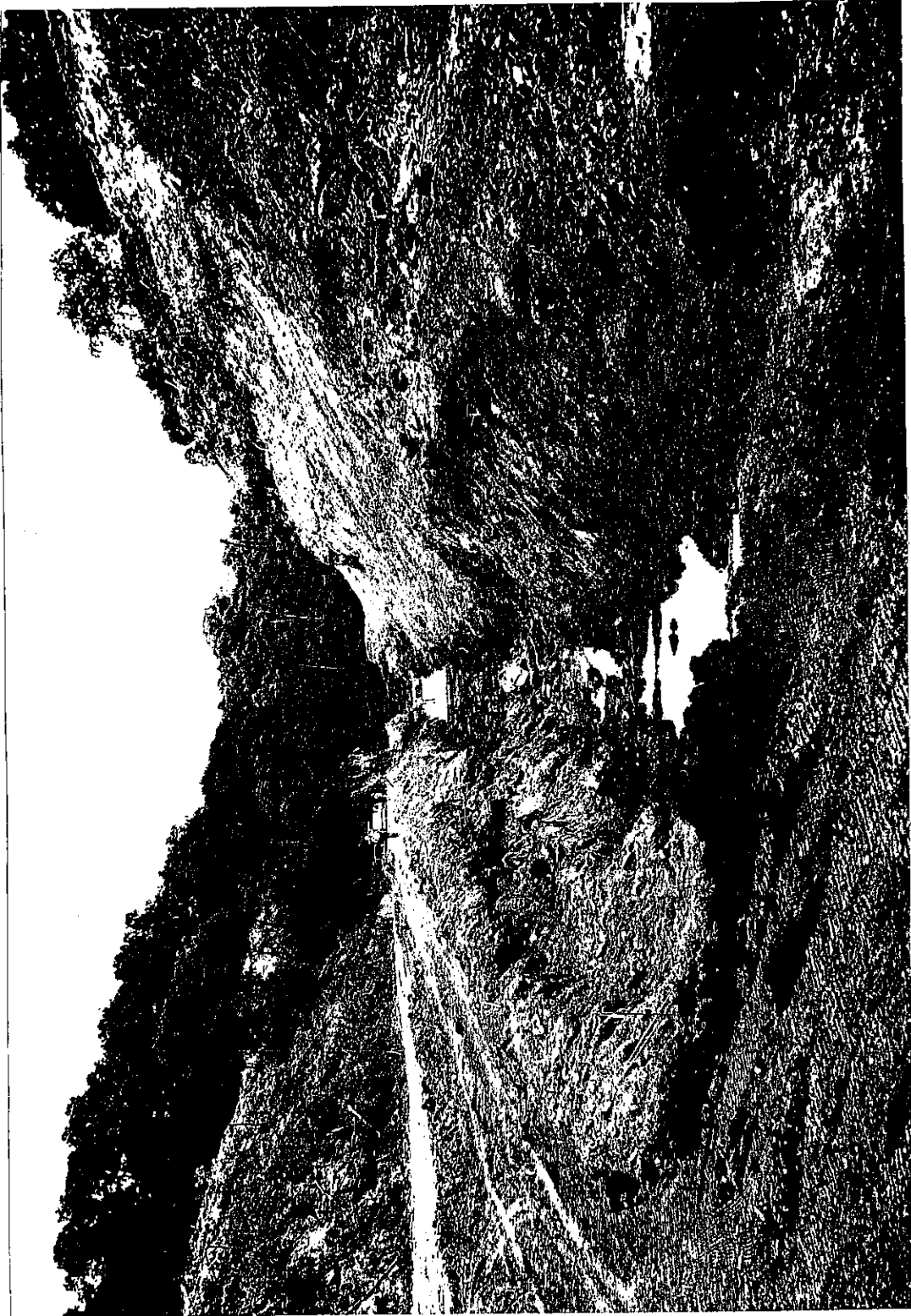


Figure 3. View of trench excavation for culvert.

of the bedrock (Figure 4). The 7- x 7-foot (2.13- x 2.13-m) reinforced concrete box culvert was then constructed in place using standard construction methods (Figure 5). Construction of the box culvert was completed during August 1976, followed by backfilling with sand; then placement of fill commenced.

When fill height became sufficient, approximately 11 feet (3.35 m) above the barrel, a 10- x 10- x 587-foot (3.05- x 3.05- x 178.92-m) trench was excavated directly over the culvert. This trench was then filled to a depth of 3 feet (0.91 m) with loose straw, followed by a 7-foot (2.13-m) layer of compressible top soil containing some sod (Figure 6). A 2-foot (0.61-m) layer of fill material was placed over the trench to provide a temporary seal covering. The remainder of the embankment was completed in the usual manner.

Several delays in embankment construction occurred due to periodic wet or cold weather. The embankment was completed to grade during May 1978.

INSTRUMENTATION

Instrumentation of the culvert construction project consisted of the following four types:

- 1) Electrical strain gauges placed transversely on the reinforcement bars inside one sidewall and the top slab totaling six gauges at one location in the barrel.
- 2) Electrical strain gauges on the exterior surfaces of the sidewalls and top slab of the culvert, totaling seven gauges at one transverse location.
- 3) Whittemore strain measuring plug devices on the interior surface of the sidewalls and top slab of the barrel, at one transverse location.
- 4) Settlement measuring devices installed in groups of three at three different fill-height locations.



Figure 4. Lean-mix concrete used to seal rock foundation.



Figure 5. Reinforced concrete box culvert construction using standard construction methods.



Figure 6. Induced trench excavation showing installation of 3-foot depth loose straw.

Individual strain gauges were placed on the reinforcement bars at three locations on the top reinforcement bars of the top slab, and at three locations on the outside reinforcement bars of one sidewall. Two other identical strain gauges were mounted on individual short units of steel reinforcement bar and imbedded in the ceiling section to complete the electrical circuits necessary for reading the gauges. All strain gauges were mounted on #7 (22.2-mm dia.) size reinforcement bars. Reinforcement bar gauge locations were ground to a smooth flat finish and gauges applied with a phenolic-epoxy bonding agent. A durable, protective covering was then applied using an epoxy-type waterproofing agent (Figure 7). The six strain gauges were mounted on four sections of reinforcement bar, which were interconnected within a single vertical plane parallel to the cross section of the culvert (Figure 8). Electrical wire cables were run from each gauge location within the sidewall and top slab to a central collection point in the top slab. The wiring was then routed through the lower surface of the top slab into a large electrical connector located within a waterproof steel box mounted on the underside of the ceiling (Figure 9).

Electrical strain gauges for gauging concrete strains were attached to the exterior surfaces of the box culvert at the same locations as the reinforcement-bar mounted strain gauges. One additional location was included at the center of the opposite sidewall (Figure 10). These gauges were located in the same vertical plane as the reinforcement bar gauges. At the gauge locations, the exterior surfaces of the box culvert were sanded smooth and flat, and an epoxy filler material was applied and allowed twenty-four hours to cure. This surface was then sanded smooth and the strain gauge, which had previously been attached to a 1- x 3-inch (25.4- x 76.2 mm) strip of .010-inch (0.3-mm) thick steel shim stock, was applied using a phenolic-epoxy (Figure 11). After a short curing time, the gauge unit plus the immediate surrounding areas were covered with a

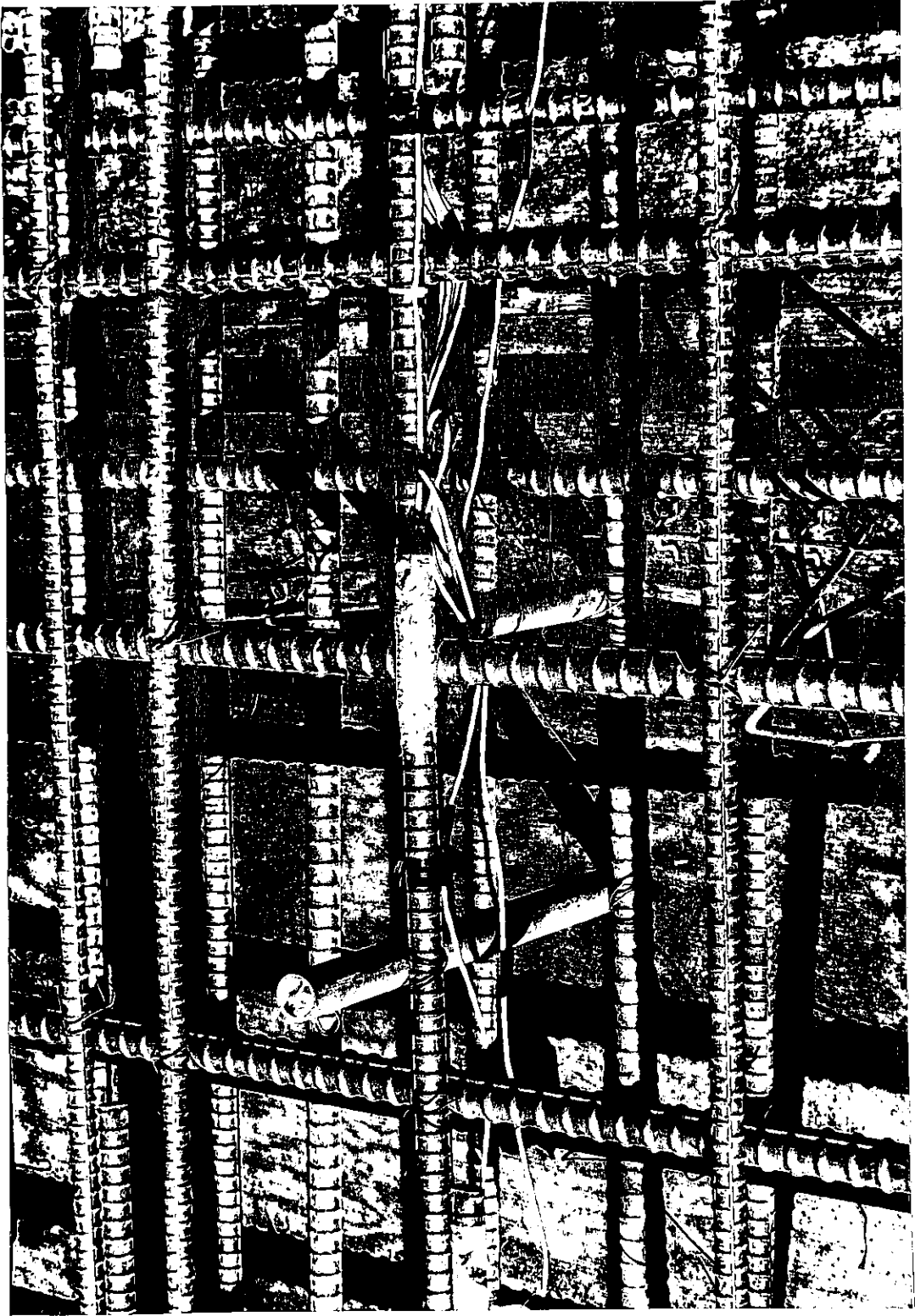
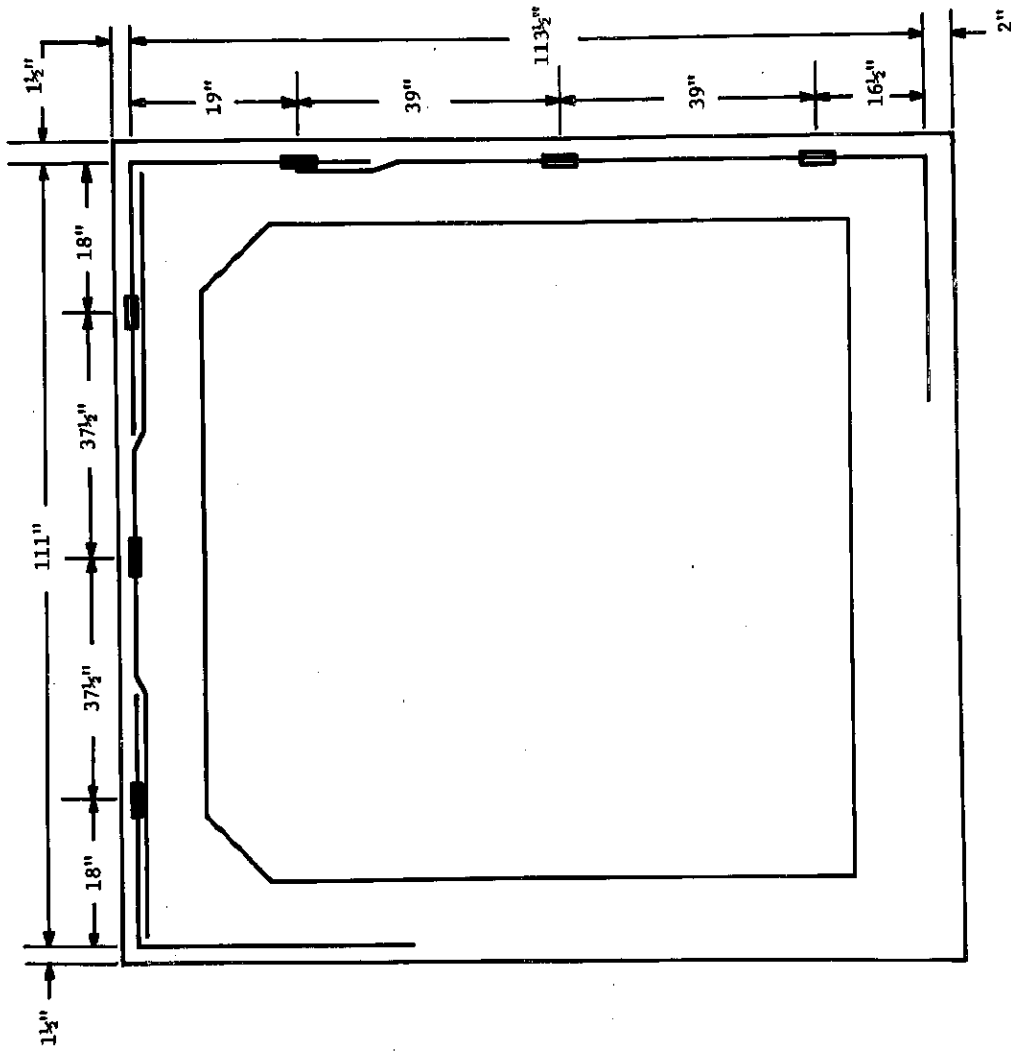


Figure 7. Strain gauge installed on reinforcement bar.



METRIC CONVERSION: 1 inch = 25.4 mm

Figure 8. Cross-sectional view showing location of strain gauges mounted on reinforcement bars.



Figure 9. Installation of waterproof connector box on ceiling of culvert.

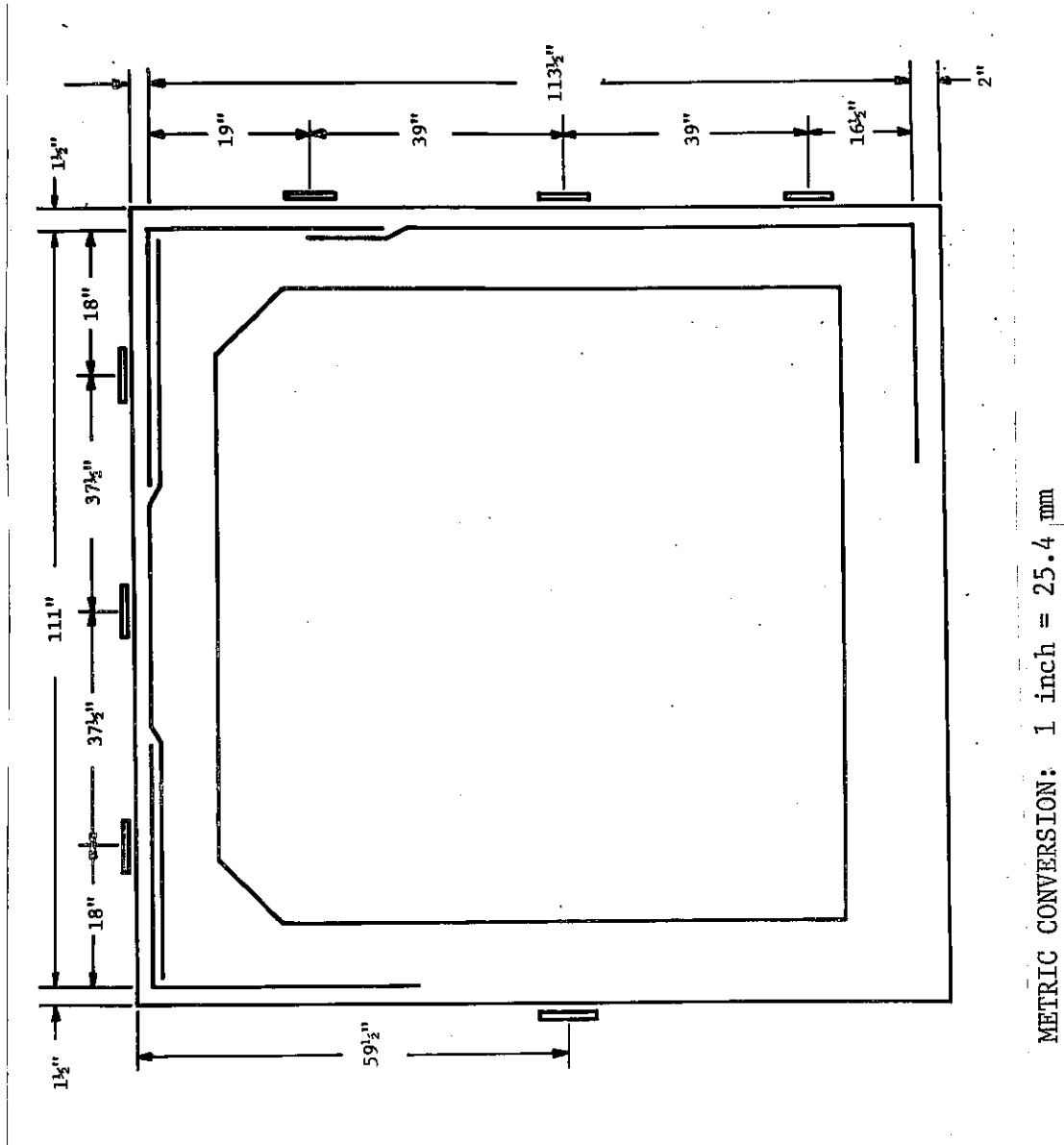


Figure 10. Cross-sectional view showing location of strain gauges mounted on the exterior surfaces of the culvert.

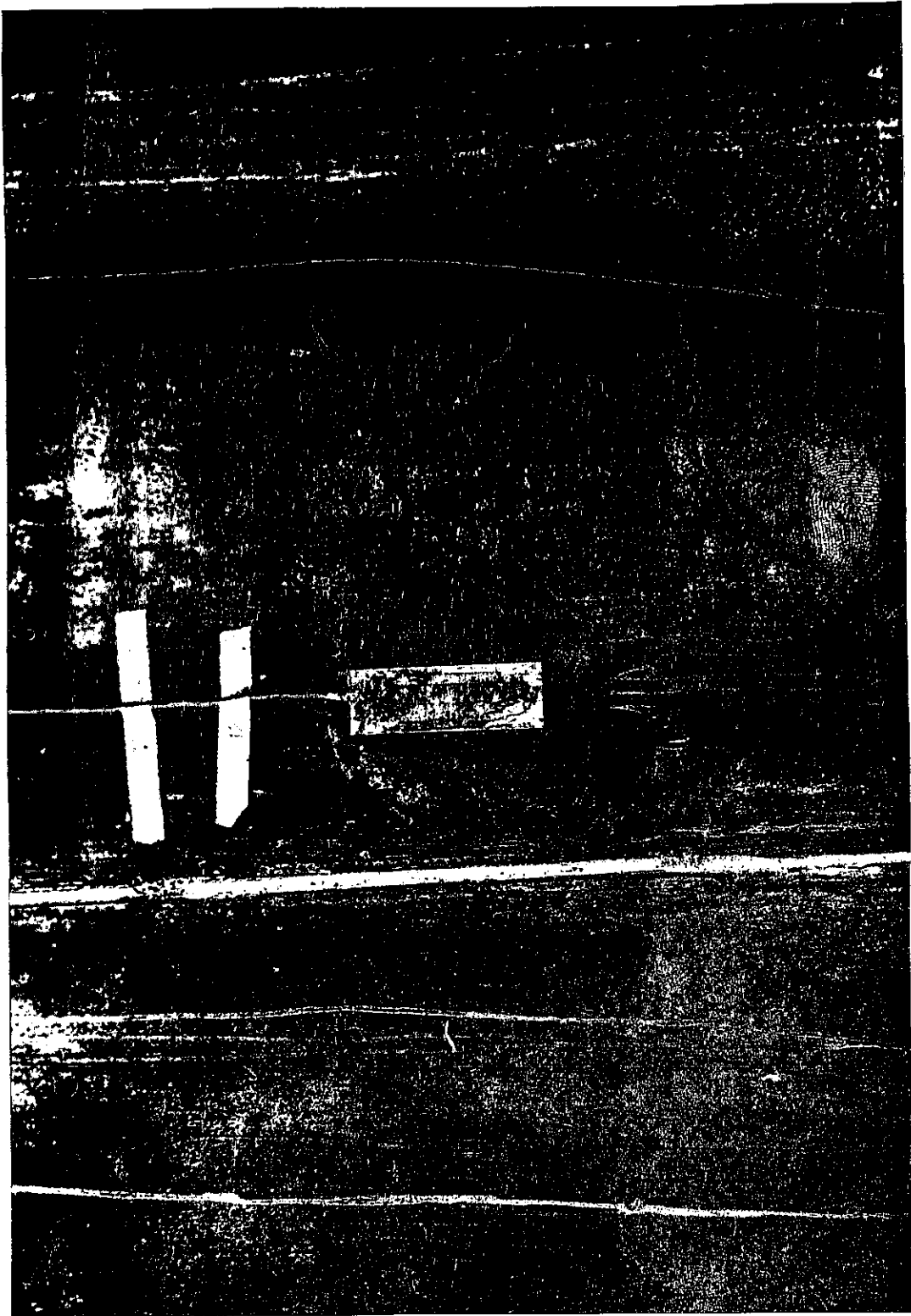


Figure 11. Strain gauge mounted on exterior surface of culvert.

commercially produced, prepackaged, waterproof pad (Figure 12). Electrical wiring was routed to a central collection point, near the center of the top exterior surface of the box culvert (Figure 13). The wires were then inserted into a small pipe, which ran through the top slab of the culvert, to the connector box mounted on the ceiling surface.

Two additional strain gauge units were attached to separate 8- x 8- x 12-inch (203.2- x 203.2- x 304.8-mm) Class X concrete blocks. These units were to be used as temperature-compensating gauges to complete the electrical circuits necessary to obtain strain gauge readings, and were originally to be placed on either side of the culvert in the sand backfill material. However, due to excessive vandalism in the construction area, these strain gauge units were replaced with other gauges which were placed inside the connector box mounted on the ceiling inside the barrel of the culvert.

Eight Whittemore strain gauge plugs were installed into the interior surface of both sidewalls and the top slab (Figure 14). The plugs are located within the same vertical plane that contains the electrical strain gauges on the reinforcement bars and on the exterior surface of the box culvert. Holes were drilled, at 10-inch (254.0-mm) centers, into the finished interior surfaces. Whittemore plugs were then inserted and secured with a quick-setting, cement-grout mixture. This installation allows a total of seven instrumentation readings per surface.

Settlement reference devices were installed in groups of three at three different fill-height locations (Figure 15). These devices consisted of a continuous vertical length of rigid 1 1/2-inch (38.1-mm) PVC pipe connected to a 24- x 24- x 1/4-inch (609.6- x 609.6- x 6.4-mm) horizontally positioned steel base plate, located on a prepared bedrock surface (Figure 16). At 10-foot (3.05-m) intervals, 24- x 24- x 1/8-inch (609.6- x 609.6- x 3.2-mm) steel settlement plates

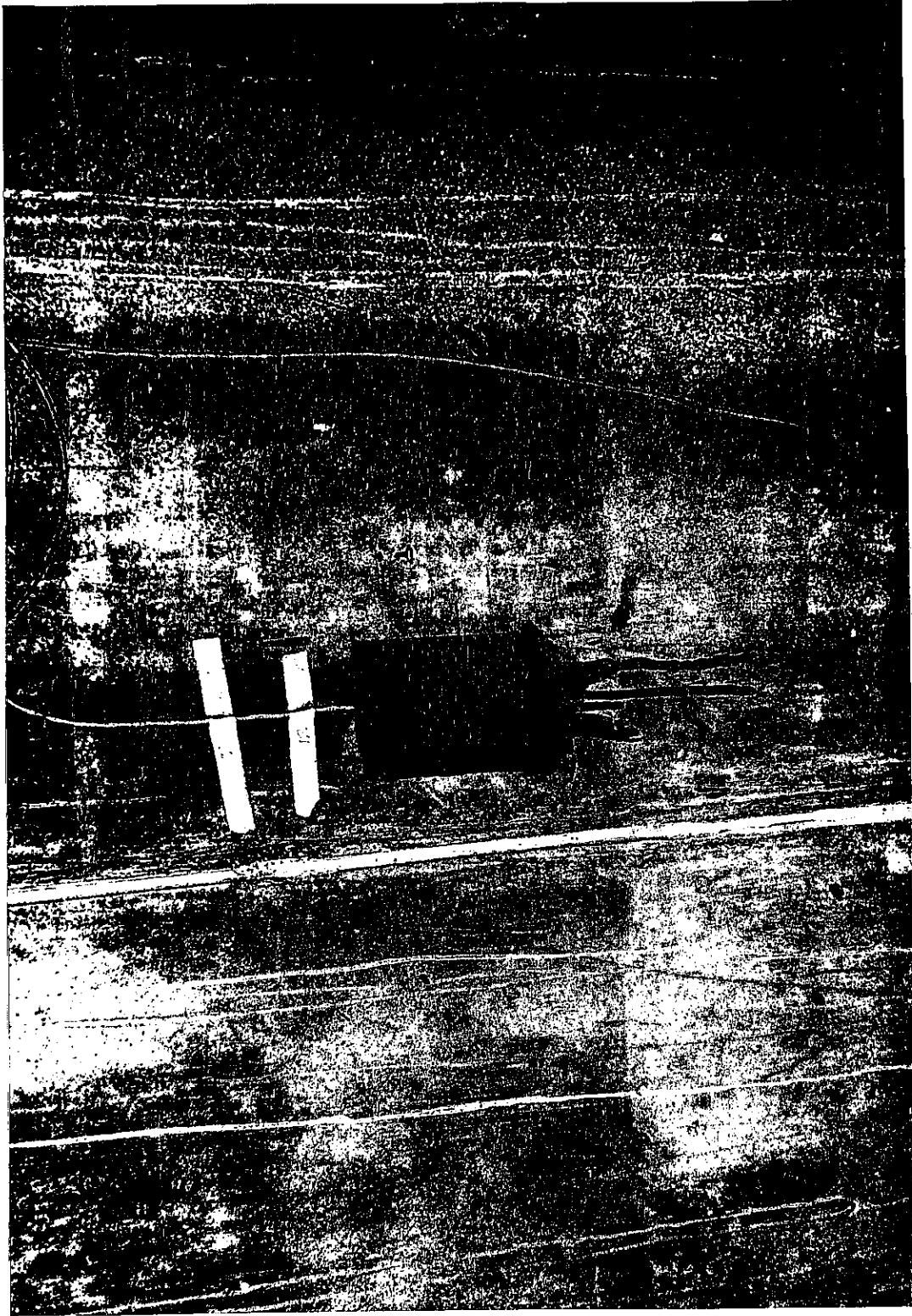


Figure 12. Waterproof covering on strain gauge mounted on exterior surface of culvert.

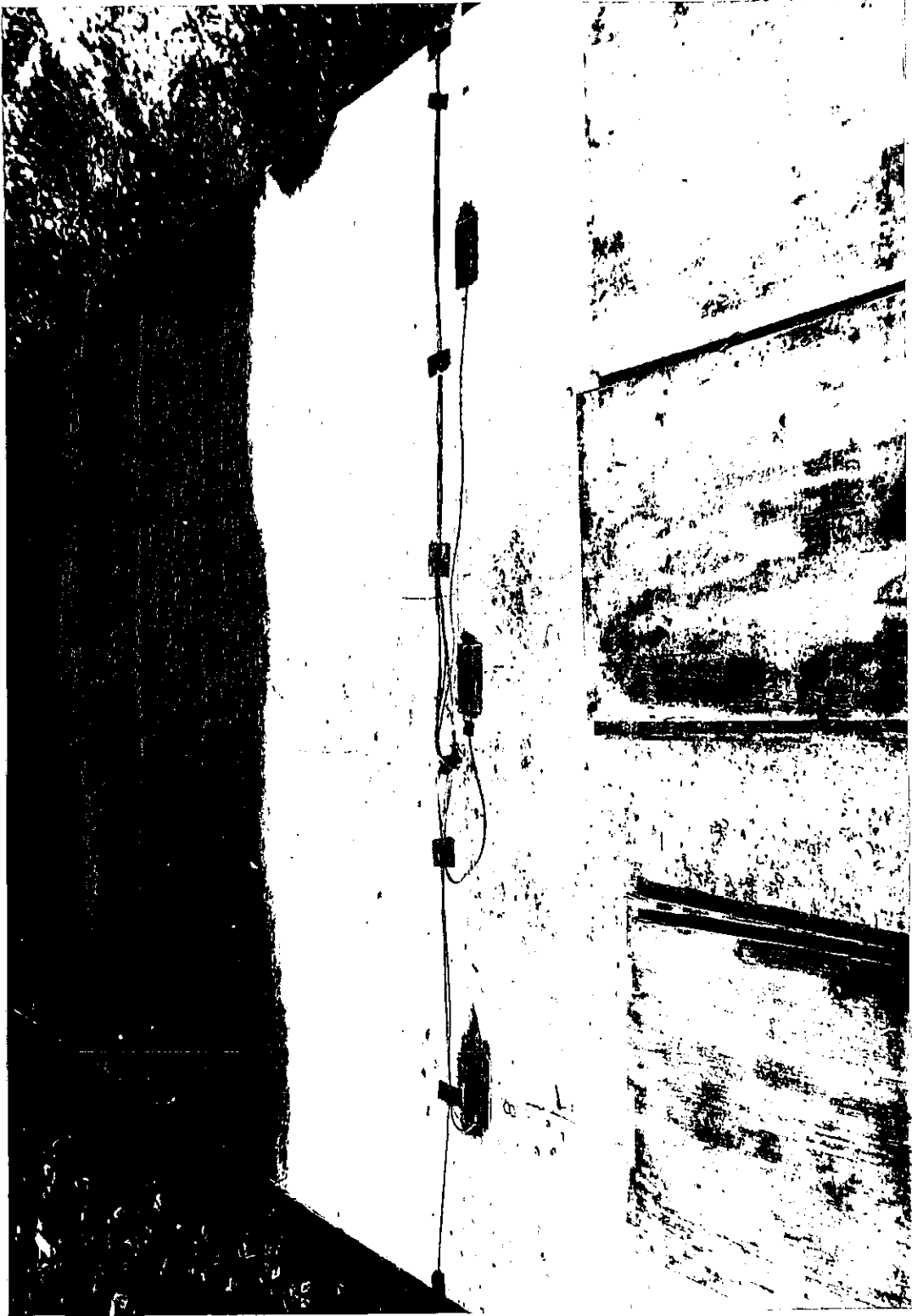
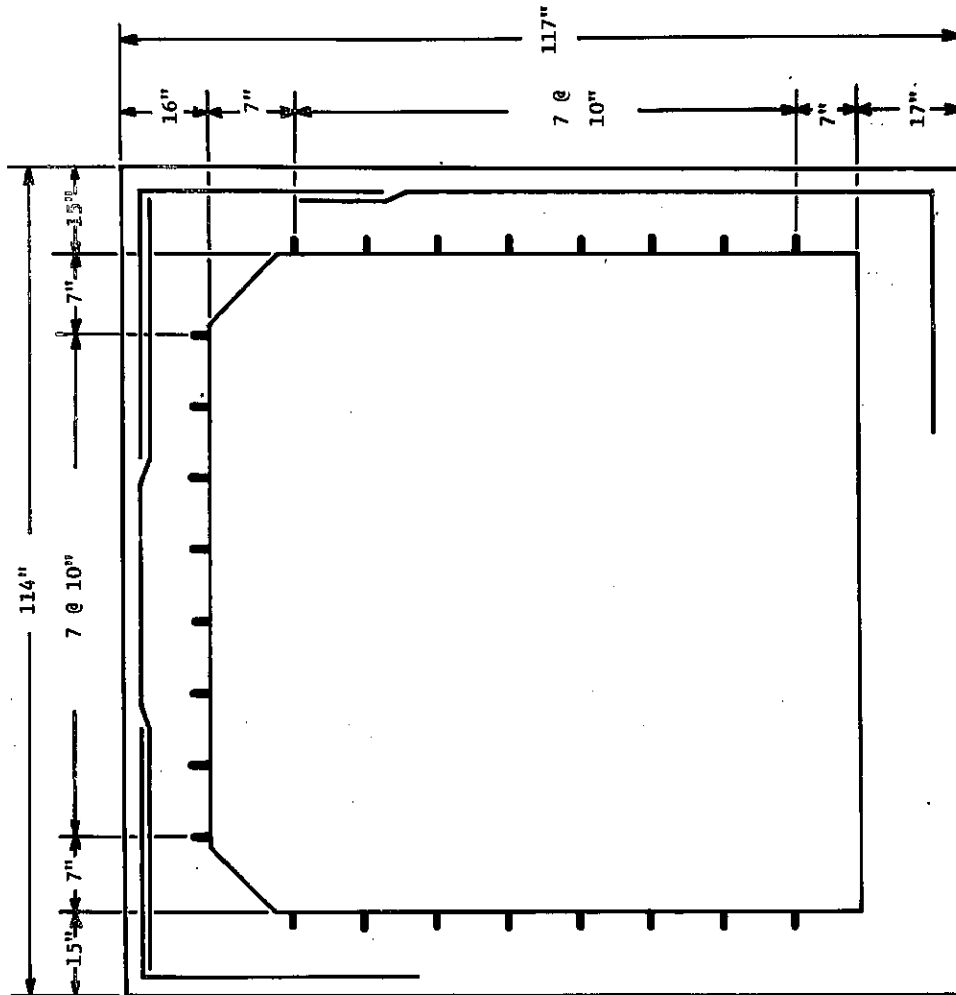


Figure 13. Concrete exterior gauges on ceiling of culvert plus waterproof covering and necessary wiring.



METRIC CONVERSION: 1 inch = 25.4 mm

Figure 14. Cross-sectional view showing location of Whittemore strain measuring plugs.

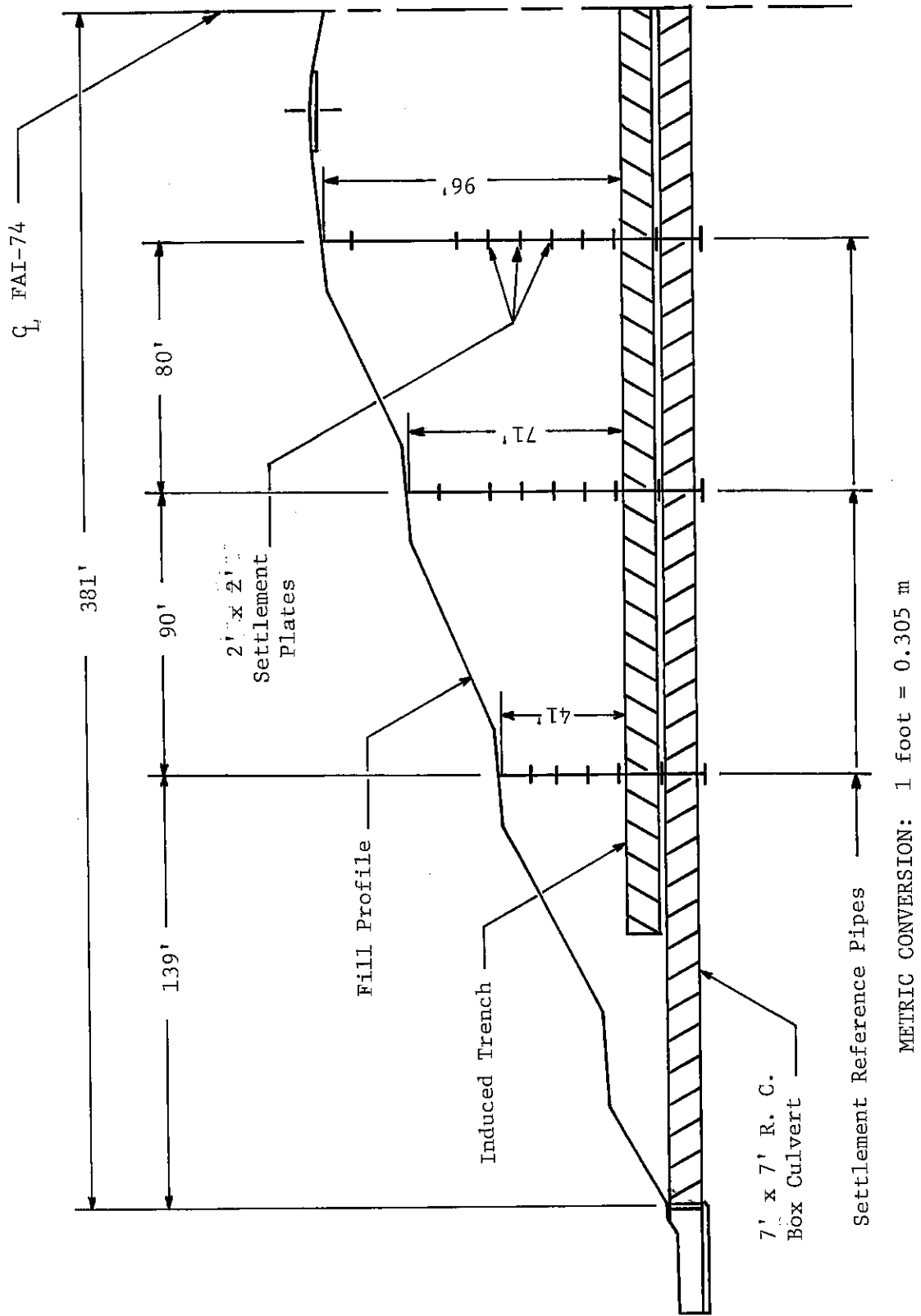
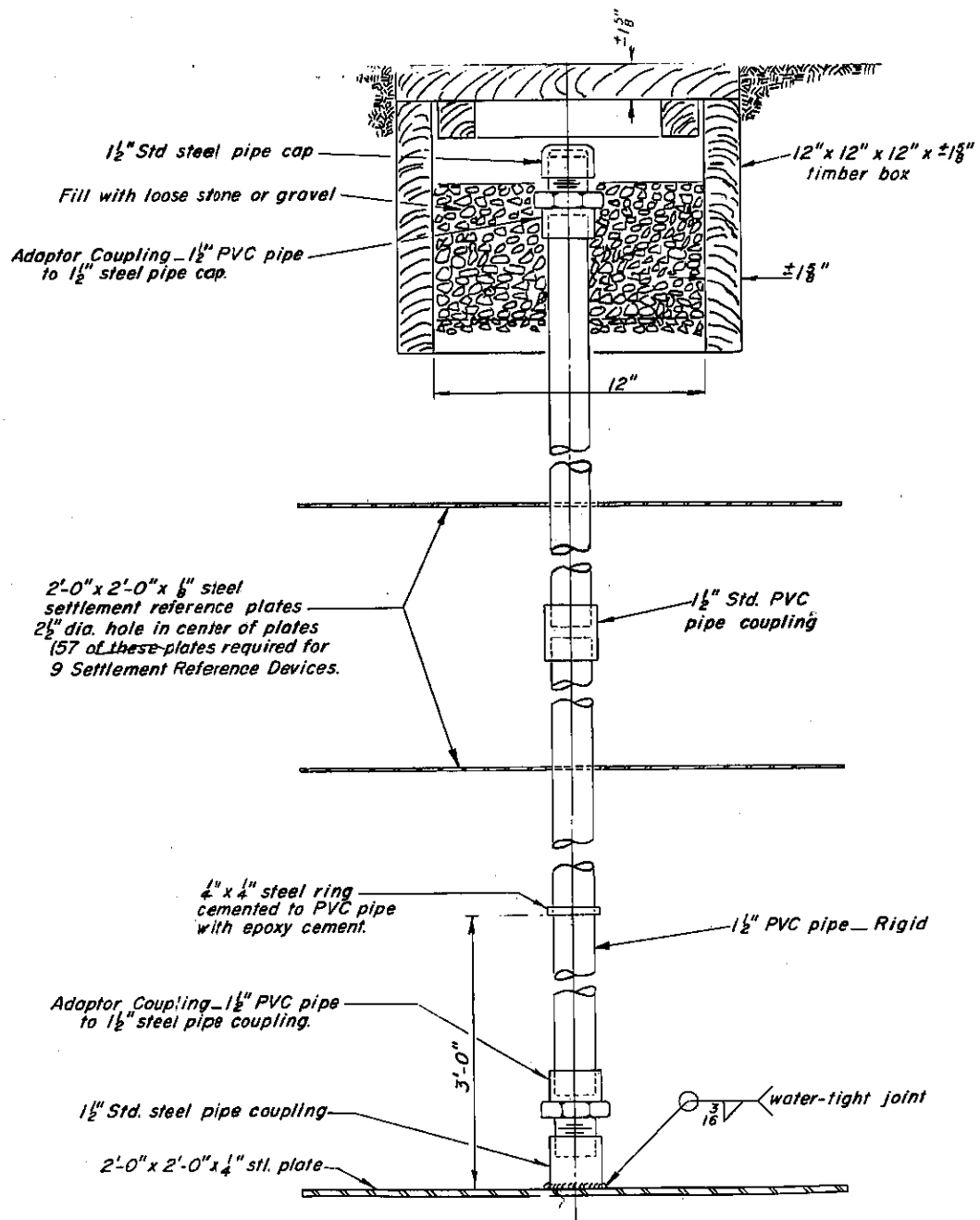


Figure 15. Diagram showing location of Settlement Reference Devices.



SETTLEMENT REFERENCE DEVICE

METRIC CONVERSION: 1 inch = 25.4 mm; 1 foot = 0.305 m

Figure 16. Settlement Reference Device construction details.

were installed parallel to the base plate. The settlement plates were placed to sufficient heights to include the theoretical plane of equal settlement at each fill-height location. These plates had a 2 1/2-inch (63.5-mm) diameter hole in the center to provide clearance for the PVC pipe. The standpipes at each location were arranged on 10-foot (3.05-m) centers, with the center settlement pipe base plate resting on the exterior surface of the finished culvert at the centerline (Figure 17). The settlement reference devices were installed in a plane parallel to the cross section of the barrel of the culvert. The devices on either side of the culvert were placed immediately prior to backfilling the completed culvert while the center standpipe was placed during the induced trench construction (Figure 18). A 1/4- x 1/4-inch (6.4- x 6.4-mm) steel ring was attached 3 feet (0.91 m) from the base plate to provide the starting point for settlement data collection using the Settlement Plate Detection Probe. A protective, recessed wooden box was placed around the top of each individual standpipe as it reached the height of the fill. Access to the interior of the box is achieved through the use of a removable cover plate.

SETTLEMENT PLATE DETECTION PROBE

The Settlement Plate Detection Probe was designed to determine the amount of movement of the settlement plates relative to their initial installation elevations. The portable device is basically a 12-inch (304.8-mm) diameter hand-operated reel, containing 120 feet (36.58 m) of cloth measuring tape, and a 3/4-inch (19.0-mm) diameter by 12-inch (304.8-mm) long electronic probe (Figure 19). The probe is attached to one end of the tape. The tape has a pair of electrical wires woven to it that transfer electrical impulses through the hub of the reel to a meter mounted on the framework. Within the probe there are three coils mounted in line. The center coil is excited by an AC signal, which is generated by an oscillator within

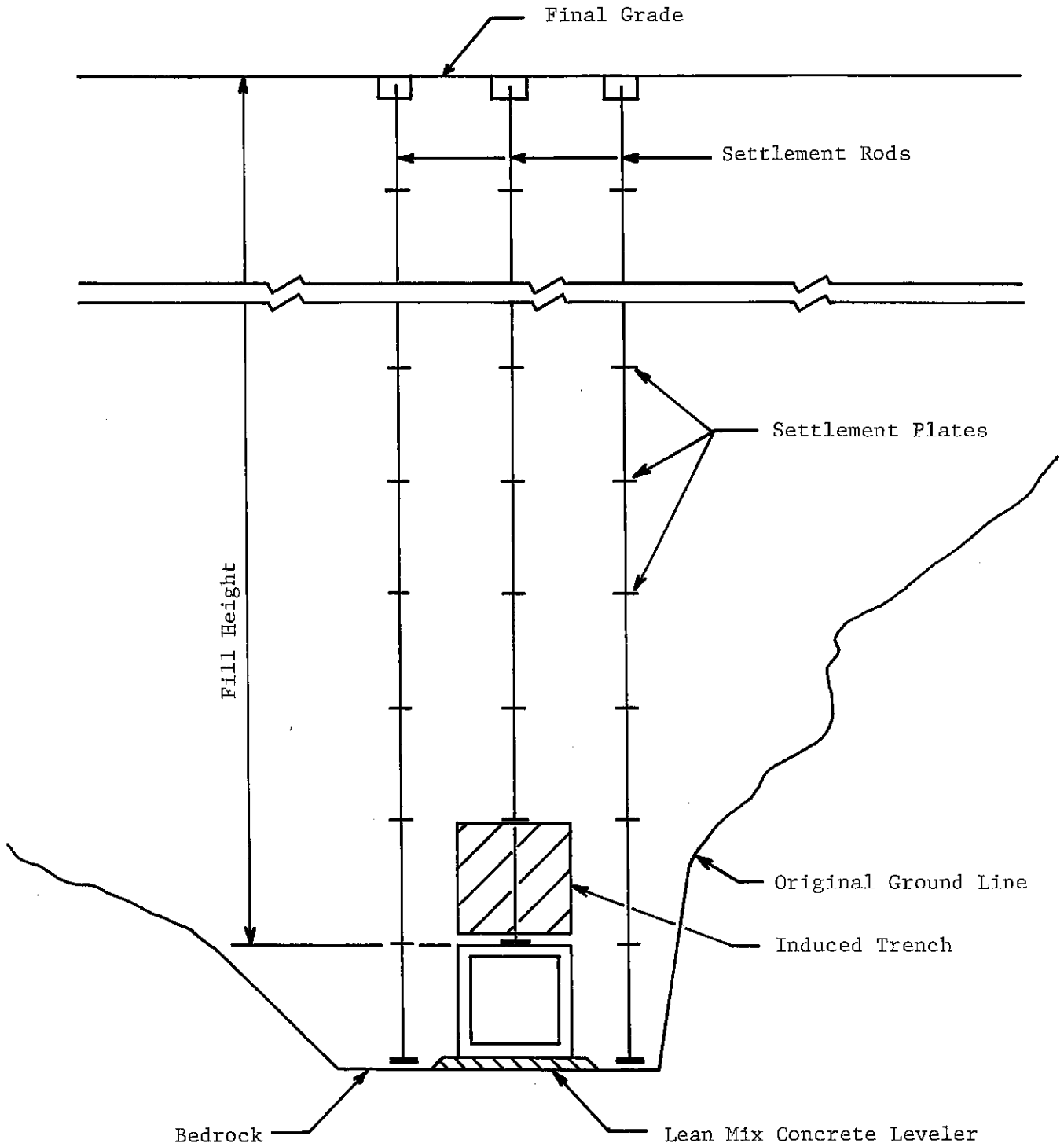


Figure 17. Typical cross section of induced trench showing Settlement Reference Devices.

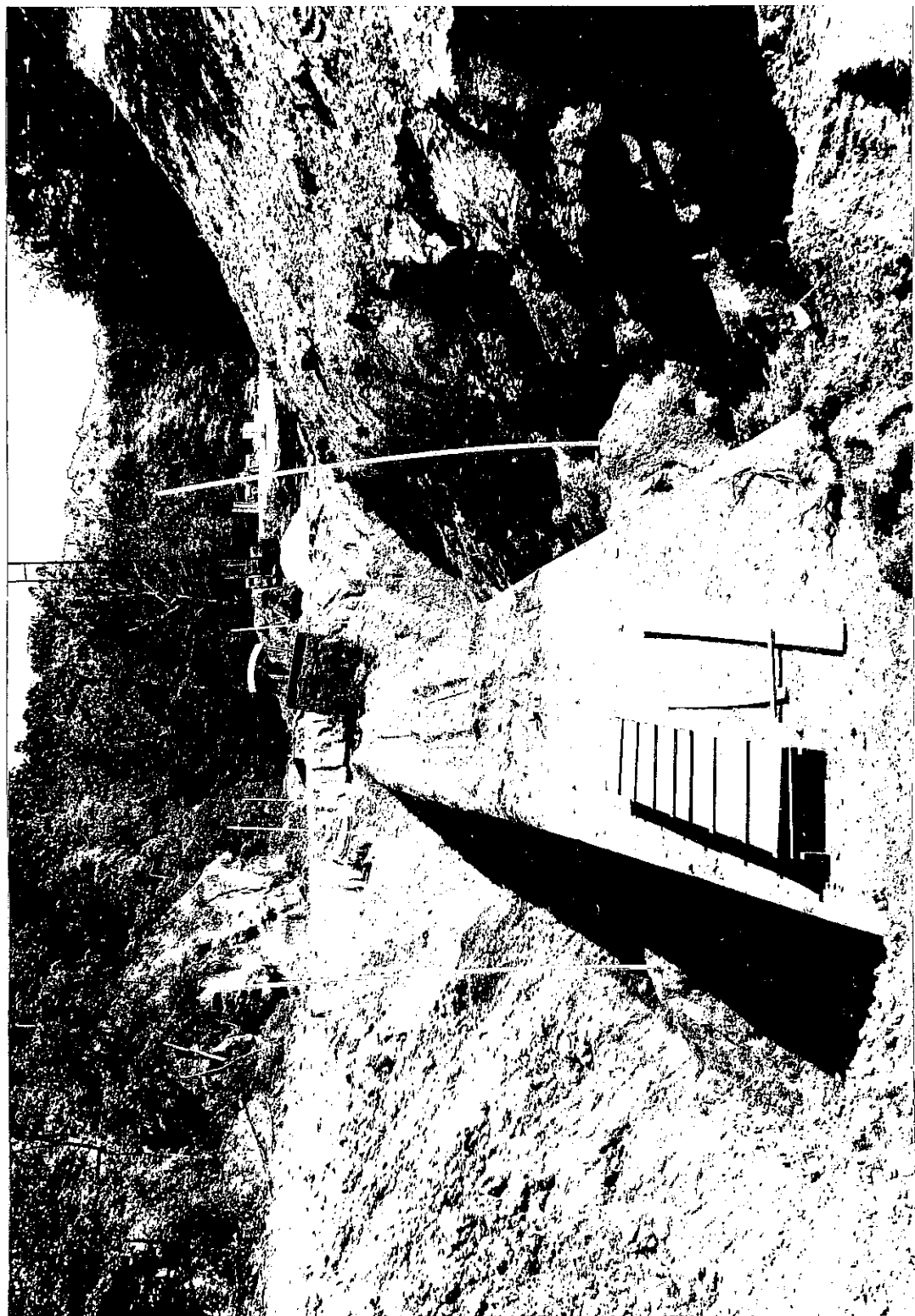


Figure 18. Backfilling with sand after installation of the settlement reference devices.

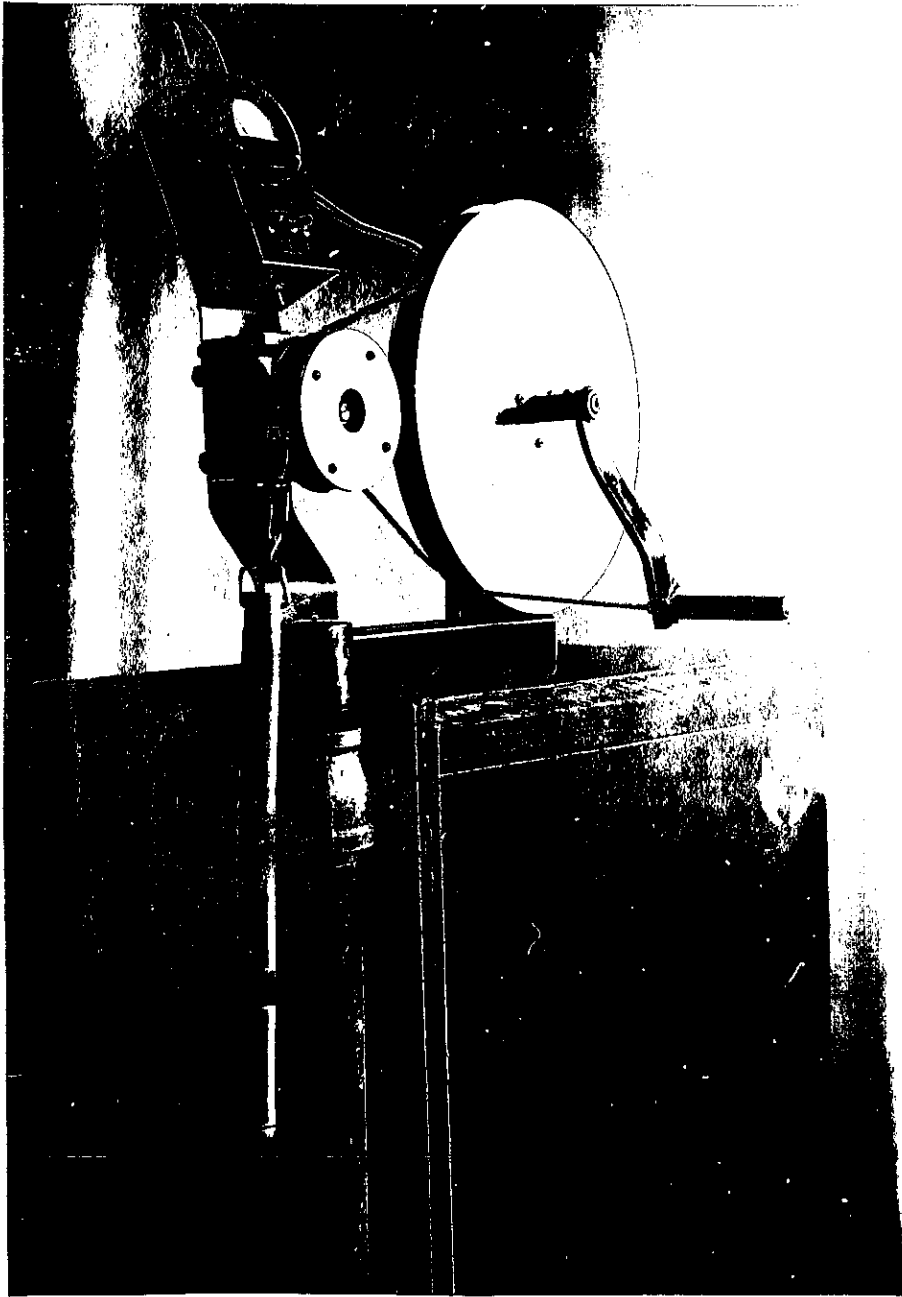


Figure 19. Settlement Plate Detection Probe.

the probe. The three coils are spaced so the two outside coils are subjected to the magnetic field produced by the center coil. Both outside coils are wired so their output voltages oppose each other. Due to a slight variance in alignment of the coils, a small voltage will exist at the output. This output progresses through a bridge detector and the output from the detector drives a meter. When the probe is lowered through the hole in a steel plate, a position is reached where the magnetic flux above the plate and below the plate produce voltages in each coil that are equal. This causes the coils to cancel each other out and a sharp null is produced on the meter. A depth reading from the tape is taken when this null occurs. Determination of movement of the individual settlement plate is calculated by subtracting this depth reading from the initial depth reading at time of installation.

PROBLEMS ENCOUNTERED DURING INSTRUMENTATION

One of the major problems encountered with the instrumentation was vandalism which occurred at least three times while extending the PVC pipe through the embankment. The site is located near a residential area which is easily accessible to many of the younger residents. In each incidence, the plastic pipe was broken at or near the ground with much of the shattered material falling inside the pipe. The fragments would tend to lodge and block the pipes at various locations throughout the height of each pipe. Several attempts have been made to dislodge the material but the probe is too large to pass through the obstructed areas. A smaller probe is being designed and fabricated which may alleviate this situation.

Another problem, excessive displacement of the PVC stand pipes during embankment compaction, was observed. This situation results in difficulty while lowering the settlement plate detection device through the stand pipe. In addition

to the probe becoming temporarily lodged at a displaced section of the stand-pipe, the constant chafing of the probe suspension cable against these sections accelerates wear and replacement of the support cable. With the use of a more rigid pipe and careful embankment compaction near the pipe during construction, the problems incurred with excessive pipe displacement should be lessened.

At least 50 percent of the electrical strain gauges placed on the reinforcement bars and the outer surface of the concrete surfaces are not functioning. The lack of data from the inoperative gauges has greatly complicated the analysis in relating strain measurements to the possible combination of loads inducing the strains. From the nature of the readings, which are very unstable, it appears that water has penetrated through the cable insulation or possibly at the connection between the cable and the gauges. This is a common problem with electrical gauges embedded in concrete or installed in an environment which is highly saturated with moisture.

RECOMMENDATIONS

The settlement plate detection device used on this project consisted of an electro-magnetic differential transformer (EMDT) which appears to have great potential as a means of measuring embankment settlements. Although some problems did occur with the instrumentation during the course of this study, the ease of using the EMDT device, and its accuracy, surpass that of other types of remote settlement gauges, such as the water-leveling devices or utilizing settlement reference rods that are extended during the construction of the embankment.

Extreme care, however, must be taken during construction to avoid excessive displacement of the standpipe when compacting the embankment near the pipe. Also, a more rigid pipe of a larger diameter is recommended when using the EMDT method for measuring settlements within earth embankments.

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